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The fuelwood market in Greece: An empirical approach

Eleni Zafeiriou[a], Garyfallos Arabatzis[b,*], Theodoros Koutroumanidis[a]

[a] Department of Agricultural Development, Democritus University of Thrace, Pantazidou 193, 68200 Orestiada, Greece
[b] Department of Forestry and Management of the Environment and Natural Resources, Democritus University of Thrace, Pantazidou 193, 68200 Orestiada, Greece

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ABSTRACT

Wood has been since ancient times the basic household heating medium. Nowadays, wood remains the primary energy source in rural areas of developing countries, mainly in Africa. In Greece, the domestic demand of fuelwood is relied mainly on the fuelwood domestic supply. Especially, during the post-war period the domestic supply satisfies adequately the domestic demand, eliminating the role of imports.

The present study surveys the long-run relationship between the fuelwood prices of different forest species in order to determine the role of the special market conditions in their price formation. In addition, the error correction model is estimated in order to survey the direction of the Granger causality among the prices of the fuelwood forest species. The implementation of the impulse response analysis and the variance decomposition confirmed that coniferous and beech fuelwood producer price may account for the volatility of the oak fuelwood producer price. This result may contribute greatly to the conservation of oak forest, an important carbon storage forest ecosystem.

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1. Introduction

1.1. Renewable energy sources

The economic growth in most developed countries is based mainly on the exploitation of energy, the sources of which are unevenly distributed around the world, a fact which at times resulted in regional conflicts. To be more specific, fossil fuel is today the primary source of energy, both for developed and developing countries, with a decisive impact on their development. Actually, empirical tests have confirmed that GDP and energy consumption (per capita), are highly correlated [1,2].

Confronting problems related to the oil crisis and the volatility of oil supply-demand, necessitated the implementation of energy policy for non oil producing countries. Common policy elements often observed in these countries are the following; the rational use of energy resources, the development of competitive energy production methods by domestic resources, and the substitution of oil as energy resource by other energy resources.

The recent switch from conventional to renewable energy sources (RES i.e. wind, solar, hydro-electricity, biomass), and their gradually extensive use is a common feature of the energy policy adopted by the developed world [3–6]. The superiority of the RES lies on their following traits: (a) they are inexhaustible either because of their great reserves or because they can be regenerated by nature or humans, (b) their use contributes to the limitation of humans' energy dependence on exhaustible resources like oil, and (c) they assist to the security of the country's energy supply and they preserve the natural environment [6].

* Corresponding author. Tel.: +30 25520 41158.
E-mail addresses: ezafir@agro.gr (E. Zafeiriou), garamp@fmenr.duth.gr (G. Arabatzis), tkoutrou@agro.duth.gr (T. Koutroumanidis).

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Within the last decades many countries and especially the oil importing countries make efforts for the sustainable exploitation of biomass (fuelwood, wood residues, crop residues and fruit residues) aiming at the oil substitution in order to limit the exchange transfers to the oil producing countries [3,7].

A brief description of the most important energy consumers and their effort to extend the use of the renewable resources is presented in the following paragraphs.

United States of America (USA) is an important energy consumer all around the world. The total consumption of US renewable energy resources has reached almost 7.89 EJ in the year 1999, an amount that corresponds to 77% of its total energy consumption [8]. In the year 2007, the US electricity production generated by renewable resources corresponded to 8% of the total production. By the year 2050 this proportion is expected to reach almost 16% [9].

The renewable energy resources are also used extensively in China, another important energy consumer. To be more specific, China covers almost 7% of its total energy needs by renewable energy resources, while the annual growth rate of the renewable energy use overcomes 25%, the highest all around the world [10].

A similar situation is observed in UK another developed country. In UK, the domestic power companies made efforts to expand the renewables capacity in order to reach 21 GW by the year 2010 and to cover 14% of the country's predicted electricity consumption for the same year [10].

Finland and Sweden use extensively forest-originated biomass. Actually, the use of biomass has increased significantly within the last 25 years and reached 20% of the primary energy supply in the year 2001 [11].

Another important renewable energy consumer is Germany. A number of policies have been implemented aiming at an Integrated Energy and Climate Program as suggested by the European Union. The contribution of renewable energy resources to the electricity generation has been increased more than four times (the share from 3.4% has reached 14.2%) within the last 18 years (1990–2007), while the share of biomass in total electricity generation has been increased almost 15 times for the same time period (the share from 0.26% in 1990 has reached 3.86% in 2007) [12].

Before the oil crisis in the year 1973, different forms of biomass (by different sources and different species), were used for the energy production in a variety of economic activities. After the year 1973 and due to the energy crisis there has been an intensive effort for the extensive use of wood wastes and residues for power generation. As a result of this effort, the biomass has become the major supplier of bioenergy in the developed world [13–15].

Even though fossil fuels remains the dominant feedstock for energy production, the traditional use of biomass as fuel has become significant, amounting approximately 10–15% of the world energy use [16]. Furthermore, 3.5% of primary energy use in the OECD is satisfied by biomass as well as 3.1% of final energy consumption. Biomass is an important source of heating for these countries, since it represents 14% of the total heating capacity they produce. The distribution of the consumption of the biomass originated energy is consumed by households a proportion that reaches 48% (mainly wood burning) and the rest with a proportion of 44% is used in the paper, pulp and wood industry sectors that use residues mainly for internal energy generation [17]. Biomass satisfies 38.1% of the energy requirements of developing countries, while in developed countries this amount reaches only 2.8% of the energy requirements [13]. The spatial distribution of the biomass consumption as a proportion of the total energy consumption is as follows: in Africa the mean amount of energy consumption reaches 62%, in South Asia 56.3%, in Europe 3.5% and in North America 2.7% [7].

Wood and wood residues that come from forests or energy plantations are the most important types of biomass [18,19]. Their significance varies from a region to another. The developing countries use wood fuels at a greater extent than the developed countries [20–23]. For instance in Turkey in the year 1990, the crude oil was first in primary energy consumption with a share of 45% of the total energy consumption and is followed by lignite (18.4%), coal (11.6%) and fuelwood (10.1%). This distribution is expected to change in the near future while the aforementioned shares are estimated as follows: lignite is estimated to come first (28%), crude oil follows (27.4%), natural gas (18.1%), coal (9.9%) and fuelwood (7.6%) [21].

In addition, in USA the oil consumption reaches 39.09% of the total primary energy consumption, natural gas 22.95%, while the consumption in wood and wood wastes consists only 2.84% of the total primary energy consumption [8].

On the other hand in India the energy consumption of a typical household comes mainly by fuelwood (75.6%) and kerosene (8.29%) [22]. In addition in other developing countries like Liberia, Burkina Faso and Tanzania the main energy resource for household activities (for the 95% of the total population) is generated by traditional biomass [24]. What also must be mentioned as last but certainly not least is the high proportion of the biomass in the total energy consumption in Ethiopia. In particular this proportion reaches 90% of the total energy consumption in the whole country and 99% in rural areas [25]. Furthermore, in Africa the energy use is related to the standard of living mainly in rural areas. Fuelwood plays a significant role in providing energy for cooking and food processing [15,26,27].

The use of wood for different purposes is characterized by an increasing trend. Worldwide, more than the half of roundwood production is used for fuel purposes [28,29]. This is valid for developing and developed countries, given the increasing need for renewable energy resources. Nevertheless, the excessive consumption of fuelwood may also have a negative impact, such as land reclamation and degradation of huge expanses of land in various regions [25,30]. This phenomenon is of great importance for the developing countries mainly in Africa. Another characteristic of the world fuelwood market is the limited international trade [31].

The main objectives of the energy policy implemented in EU are the following:

- Safety in the energy supply.
- Competitive prices and low cost in energy generation.
- Energy consumption in an environmental friendly manner.

All the objectives regarding the increase of RES as a share of total energy consumption by its members are quite ambitious and are expected to be realized by issuing a number of directives.

The directive 2001/77/EC [32] of the European Parliament and Council aims at the promotion of RES as electricity energy resource within the European market. The main objectives of this directive is the introduction of a framework in order the production of the green electric energy to be increased from 14% to 22% as a proportion of the total energy consumption until the year 2010.

The other directive of EU regarding the biofuels (2003/30/EC) [33] determined the increasing participation of biofuels until it reaches the amount of 5.75% having as a time reference the year 2010. The implementation of this directive contributed to the introduction of an institutional framework that launches the extensive use of biofuels in the market.

Finally, the current directive intends to substitute the conventional energy by RES generated energy. The distribution of this amount should be based on the potentials of each country member. On the contrary, it is compulsory for every European country to substitute the conventional energy by biofuels energy in trans-

portation.The rates in the liberalization of electricity markets and the use of supply systems, based on renewable energy sources, vary within the European Union. In most cases a country specialize in one or two renewable energy sources, according to local and national geographical and natural conditions (raw materials, climate, relief). For instance, Sweden and Finland have exploited the biomass as energy source given the developed forestry. Countries like Denmark, Hungary, Germany, Finland, Sweden, Latvia have almost achieved the targets set for the year 2010 regarding the participation of the renewable energy sources in the energy consumption of each country. Greece on the other hand, is far from achieving the target of 20.1% in the year 2010, despite the great interest in investments for renewable energy sources [34].

The European Committee is committed to present an Action Plan about the biomass as stated in a report of the year 2004 for the renewable energy sources. The Action Plan was implemented in the year 2005 and set as a target to increase the energy production that comes from biomass and in particular by wood, wastes and agricultural cultivations [34]. Nowadays, EU satisfies only 4% of its energy needs by biomass. This percentage can be doubled if this potential is being fully exploited.

In many European countries, incentives and financial motives are provided in order the use of renewable energy resources to be enhanced. Examples of these motives are special pricing for bio-electric energy, subsidies and non-interest loans for special environmental capitals, as well as tax motives for investments [34]. Furthermore, bioenergy is considered to be vital for the sustainable development of rural areas. Thus, the gradual Common Agricultural Policy (CAP) reforms contribute greatly to the increase of the production of rural biomass [35]. In addition the subsequent CAP reforms within the last few decades encouraged the afforestation of agricultural and other non cultivated lands that resulted in the increase of the production of the forest biomass. In addition with CAP reform in the year 2003, subsidies were introduced for energy plants so that the production of the agricultural biomass to be motivated [34].

In Greece, the main limitations for the extensive use of the RES are the existent bureaucracy and lack of infrastructure. The situation has been improved though, within the last few years especially in issues related to the process of a license issuance needed for the function of a RES project [6].

1.2. The fuelwood market in Greece

In Greece, the energy needs are satisfied mainly by oil imports, a limitation to the economic growth of the country [2,36,37]. The use of renewable energy sources (RES) can change and improve the existing situation, though.

The forests in Greece are a major source of biomass and, according to the latest census; they cover 3,359,000 ha, i.e. 25.4% of the country's total area (Ministry of Agriculture [38]). The ownership and the means of exploitation of the forests vary from a country to another, depending on its socio-economic, historical and political conditions. In Greece, the state forests are the main type of ownership, since they occupy 65.5% of the total forestland. The rest of it that corresponds to 34.5% is distributed as follows: 12% are municipality properties and 8% are private while 14.5% is owned by monasteries and joint forest property. Greek forest lands in addition, include protected areas like national parks, aesthetic forests, etc. [38].

In the year 1994, the industrial wood production is 654,675 m^3 while in the year 2004 the same type of wood production reaches the amount of 380,931 m^3. As far as the production of wood fuel is concerned in the year 1994 was about 1,447,831 m^3 and 10 years later 1,223,764 m^3. In the year 1994 the production of industrial wood corresponded to 31.1% of the total wood production in Greece (industrial + wood fuel), and this amount reaches 23.4% in the year 2004.

On the contrary, the fuelwood production as a proportion of the total wood production is characterized by an increasing trend since from 68.9% in the year 1994, reached 76.6% in the year 2004. However, the apparent consumption (production + imports − exports) of the industrial wood has risen significantly (due to great amount of imports) for the time period 1994–2004 not only in absolute but also in relative terms [39].

Finally, the share of the industrial wood in the apparent consumption as analyzed above within the same reference period has risen from 55.2% (in 1994) to 69% (in 2004) while a decrease of the wood fuel share is recorded.

The domestic use of biomass (wood) (755,000 tons oil equivalent), mainly for cooking and heating purposes for residential use, accounted for about 75.1% of the estimated energy (1,005,000 tons oil equivalent) produced from biomass in 2007, while the rest is used in the industrial sector for the same needs (CRES [40]).

Furthermore, the price explosion of oil and gas prices has given a push to the use of renewable energy resources. Indeed, the share of renewable energy resources (RES) in energy supply presents an increasing trend.

In Greece despite the decreasing trend of the fuelwood consumption in total (Ministry of Rural Development and Food [39]), the fuelwood consumption in urban regions presents an increasing trend due to the fireplaces used in residences [41,42].

In Greece, as well as in other Mediterranean countries oak forests are the dominant forest type. The forests of oaks occupy almost 1,500,000 ha, that corresponds to 44% of the total forest area of the country. Kermes oak and Holm oak are two other evergreen species that cover a significant proportion of the Greek forest land. The main use of oak forests is the production of fuelwood and charcoal [38,43]. Thus the quantities of the fuelwood produced by oak wood are greater than those produced by beech and other coniferous species (spruce, fir, pines). The prices of all the wood categories (long length roundwood, fuelwood, etc.) produced and supplied by the state forest farms (sellers), are formatted within a free competition (in the wholesale market) among the buyers and is taking place with auctions organized the Regional Forest Services within the framework of the state forest exploitation. The state forest farms organize auctions of the fuelwood in different places of the Greek region. The mean annual prices of those auctions are the negotiation prices for the wood supply produced by non state forestry, as well as for wood cut, harvested, and transported by the Rural Forest Cooperatives [36,44].

The price of the oak fuelwood is greater than the price of the other two species. In addition the price of the beech fuelwood is greater than the price coniferous fuelwood.

In Greece within the last decades, a decrease in the production of the oak fuelwood is observed, a phenomenon that concern in general the fuelwood and is attributed to the rural forest cooperatives woodcutters' preference to the production of the technical–industrial wood (conifers, oak). This preference is related to the higher price of this type of wood.

In the past the oak forests in Greece, has been a subject to intensive exploitation due to extreme wood cutting, and over-grazing having as a result their degradation and sometimes as bushes. The regulation though of the wood cutting and especially with the limitation of grazing especially by the small ruminants there has been a natural rectification. Thus, the bush formation has been substituted by wonderful ecosystems consisted by oak and other forest species. With only a few exceptions, the oak forests still produce fuelwood as the main wood product [43].

In general, an oak forest as a carbon stock is considered to be more stable from ecological point of view. In addition, the oak

forests in their maturity age have the ability to absorb carbon dioxide in greater quantities than other species [45,46].

The main objective of this paper is to survey the interrelationships of the fuelwood prices of different forest species in order to survey whether the fuelwood market is integrated and to determine whether other factors affect their price formation. The forest species used in this study are the following: conifers, oak and beech. In particular, the present paper studies fuelwood prices of different forest species with the application of cointegration technique, the estimation of the Vector Error Correction Model in order to determine Granger causality between the variables studied, an impulse response function is estimated, a tool for describing the dynamics in a time series model by mapping out the reaction in, the oak fuelwood price to a one standard deviation shock to the beech or coniferous fuelwood price respectively, while a variance decomposition analysis was conducted through which a decomposition of the variance of the forecast errors of the variables in the VAR at different time horizons is achieved.

1.3. Literature review

Within the last decades, the events in the Persian Gulf and recent developments in econometric techniques, have lead to a renewal of interest in the literature related to energy consumption and economic growth [47–50]. Johansen cointegration is a technique that has been extensively used in the study of energy issue. This technique examines whether two or more time series are characterized by co-movement in the long term. The particular econometric technique, allows us to deal with models that involve two or more endogenous variables. A number of other advantages have been recorded, the most important of which are the following:

- *Flexibility*: it can capture a rich dynamic structure and interactions.
- *Robustness*: can deal with $I(0)$ and $I(1)$ variables avoiding much of the pre-testing problem. In addition it can cope with testing for and estimating multiple cointegrating vectors.
- *Ability to test hypotheses*: it can test restricted versions of vectors and speeds of adjustment.

A bulk of energy studies are based on the cointegration technique, while they focus especially on the relationship between economic growth and energy consumption for different countries and regions [51–55]. In a recent study, the existence of one long run equilibrium relationship between real GDP, renewable energy consumption, real gross fixed capital formation, and the labor force is surveyed and confirmed with the application of heterogeneous panel cointegration test while all the respective coefficients are found positive and statistically significant. In addition, the application of Granger causality confirmed a bidirectional relationship between the energy consumption and economic growth in the short and in the long run [51]. The same causal relationship between electricity consumption and economic growth has been surveyed for seven countries of South America [55]. The Bounds cointegration approach and the Toda–Yamamoto Statistical inference in vector autoregressions have also been used to examine the causal relationship between energy consumption and economic growth for nineteen African countries [49]. Toda–Yamamoto test is an alternative to Granger causality test that is based on the Granger causality equations but augmented with extra lags determined by the potential order of integration of the series causally tested [56]. An analysis of the causal relationship between economy and energy by adopting a Vector Error Correction Model for non-stationary and cointegrated panel data with a large sample of developed and developing countries and four distinct energy sectors is another interesting study [52]. According to the results of the aforementioned study, the alternative country samples hardly affect the causality relations, particularly in a multivariate multi-sector framework. A similar econometric analysis is employed by other studies [54]. In addition the generalized variance decomposition and impulse-response analysis is used in order to examine the inter-temporal link between energy consumption and income in six developing countries [57]. In particular there has been an effort to examine whether income growth and energy consumption contain considerable information to predict each other. On the other hand, another study proposes a semi parametric analysis for the study of the relationship between energy consumption per capita and income per capita for an international panel dataset [58]. The results give little evidence for the existence of an environmental Kuznets curve for energy consumption. As it is known, an environmental Kuznets curve represents graphically the relationship between per capita income and the use of energy in the case mentioned above. Thus, according to the shape of this curve, energy consumption increases with income for a majority of countries and then stabilizes for very high income countries. Neither changes in energy structure nor macroeconomic cycle/technological change seemed to affect the energy consumption [59].

Energy prices in addition have been a subject of extended study with the same method [59]. For instance, with the use of the asymmetric cointegration approach is studied the long-run relationship between vegetable oil prices and conventional diesel prices in the EU for the period 2005–2007 [60].

Co-movements and information transmission among the spot prices of four precious metals (gold, silver, platinum, and palladium), oil price, and the US dollar/euro exchange rate have also been surveyed, in a study that evidence of a weak long-run equilibrium relationship but strong feedbacks in the short run were found [57]. The cointegration technique has also been used for the study the energy pricing mechanism in China [61]. In particular, the relations between Chinese energy prices and energy consumption have been surveyed having as a conclusion that the Chinese government should deepen the reform of pricing mechanism for energy and increase the energy prices reasonably to save energy.

The study of the fuelwood market in developing countries was based mainly on the demand supply theory [62,63]. In one of them a prediction of the fuelwood production and consumption is attempted based on the market conditions, prices, labour opportunities, availability of substitutes, and a measure of access to the basic resource [63]. In another study, a survey on the fuelwood sellers of Philippines is conducted and an effort to trace the main causes of differentiation in retail prices is made [62]. Another issue that attracted great interest refer to the dynamics of the fuelwood prices in India [64]. In the aforementioned study policy implications are made in order to limit the significant increase in the fuelwood prices related to the decrease in supply of fuelwood due to degradation and depletion of forests [64]. In addition, a few studies of fuelwood dynamics focus on the domestic end-user [65], while others measure fuelwood extraction rates from specific forests or areas [66] or analyze the nature of the fuelwood supply chain [67,68]. The issue of diversity in fuelwood species as an indicator of quality of natural forest fuelwood supplies, has not been a subject of study with exception that of fuelwood extraction [66]. Sub-sector analysis, which focuses on specific links in market chains rather than the specific enterprises, is particularly applicable to the analysis of such a market chain. Making focus on the input and output linkages of the enterprises in a specific level of the market chain, proved to be particular facile in the analysis of market dynamics where small enterprises dominate [69].

Finally, the regional distribution of prices on the commercial wood-fuel market for district heating plants and the pellets market for single family houses has also been a subject of study [70].

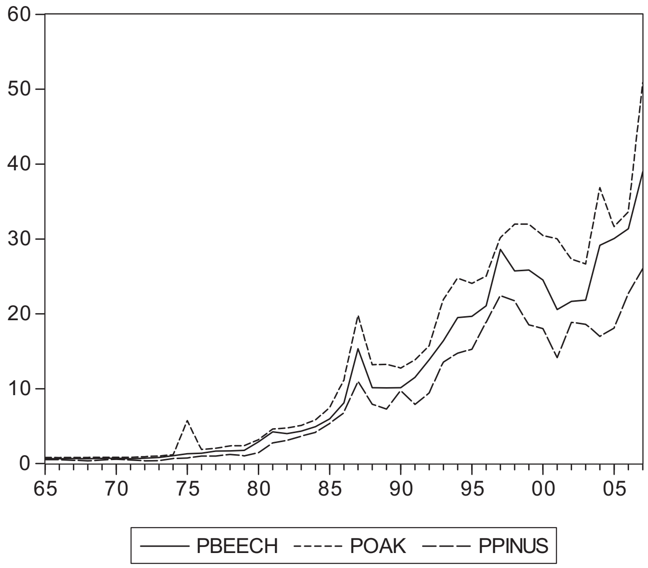

Fig. 1. The evolution of the beech, oak and conifers fuelwood prices in Greece.

2. Data

The data used in the present study are the mean annual prices of fuelwood by different forest species (conifers, oak and beech) for the time period 1965–2007. The particular prices are formatted in sale auctions of forest products. For each one of the three forest species, the data source is the Forest Regional Service. The final prices are the weighted mean prices while as weights are used the auctioning quantities.

In Fig. 1, is presented the evolution of the prices within the time period studied. The co-movement of the fuelwood prices of the three forest species implies common factors determining the prices.

The aforementioned data are employed for the study of the fuelwood market in Greece.

3. Methodology

The survey of the behaviour of the fuelwood prices of the three different species is based on the Johansen cointegration technique. A pre-condition for the application of this method is that the time series under preview are $I(1)$ or $I(0)$. This means that the time series studied are non-stationary in levels and stationary in first differences, or just stationary in levels (in case the time series is $I(0)$). Stationarity for the time series is surveyed with the application of different unit root or stationarity tests [71–73]. The first test employed is the ADF test. This test has been widely used for testing the existence of a unit root in the time series studied.

This test is based on the following auxiliary regression of the general form:

$$\Delta p_t = \gamma_0 + \gamma_1 t + \gamma_2 p_{t-1} + \Xi(L)\Delta p_{t-1} + e_t \tag{1}$$

where

$\Xi(L)$: pth order polynomial in the lag operator L
$e_t \sim N(0, \sigma^2)$

The particular test aims at testing the null hypothesis that $\gamma_2 = 0$ which is tantamount for a single unit root in the data-generating process for any variable p_t. In order to determine the ADF form we used the Akaike and the Schwartz–Bayesian (SBC) criterion. For every time series we chose the model, for which the Akaike and SBC criterion have the lowest value. According to the results of this process we determined the final form of the auxiliary regression that includes a constant and a time trend for all the variables employed.

The next unit root test employed is the Phillips Perron test which is based on the following regression:

$$\Delta q_t = \beta_0 D_t + \pi q_{t-1} + u_t \tag{2}$$

u_t is $I(0)$.

The critical values in the test are modified and are presented in the following equations:

$$Z_t = \left(\frac{\sigma^2}{\lambda^2}\right)^2 * t = \left(\frac{\sigma^2}{\lambda^2}\right) * \left(\frac{T * S.E.(\gamma_2}{\sigma^2}\right) \tag{3.1}$$

$$Z_\pi = T_\pi - \frac{1}{2}\frac{T^2 S.E.(\hat{\pi})}{\hat{\sigma}^2}(\hat{\lambda}^2 - \hat{\sigma}^2) \tag{3.2}$$

A major advantage of this test is that there is no need for the determination of the lags for the regression employed for the test while its robustness to heteroscedasticity is the main disadvantage of the test.

The last test employed is a stationarity test the KPSS test [72]. This test is based on the following model:

$$q_t = \beta_0 D_t + \mu_t + u_t \tag{4}$$

$$\mu_t = \mu_t - 1 + \varepsilon_t, \quad \varepsilon_t \sim WN(0, \sigma_\varepsilon^2) \tag{5}$$

Under the null hypothesis the variable studied is stationary while the statistic employed is given by the following formula:

$$\text{KPSS} = \frac{T^{-2}\sum_{\tau=1}^{T}\hat{S}_t^2}{\hat{\lambda}^2} \tag{6}$$

Through the aforementioned test we can conclude whether the time series studied are either $I(1)$ or $I(0)$ and consequently their combination can be tested for stationarity with the application of Johansen cointegration technique.

The VAR model for each price index is denoted by x_t ($p \times 1$) and is given by the following equation:

$$\Delta x_t = \Gamma\,\Delta x_{t-1} + \Pi x_{t-2} + \mu + \varepsilon_t \tag{7}$$

where $\varepsilon_t \sim N_p(0, \Sigma)$, $t = 1, 2, \ldots, T$

Furthermore, the following hypotheses are valid [73]:

$\Pi = \alpha\beta'$, a, b are $p\,x\,r$ matrices

The main objective in this procedure is to determine the rank of the matrix β.

The procedure of Johansen provides the maximum likelihood estimates of α, β, while Π and the two likelihood ratio test statistics determine the rank of the cointegration space. The trace and the maximum eigenvalue statistics are used to determine the rank of Π and to reach a conclusion on the number of cointegrating equations, r, in our VAR system. Given that the time series studied are $I(1)$, according to the results of all the unit root tests employed, we can use Johansen technique to examine whether there is a combination (linear relation) of the variables that is stationary. In this case the variables studied are cointegrated and hence, there is a long-run relationship between them.

As it was already mentioned above, the cointegration technique can be applied since the time series are non-stationary in levels and stationary in first differences. The Johansen cointegration technique [74,75], involves testing the null hypothesis that there is no cointegration against the alternative that there is cointegration. In order to apply the Johansen technique it is necessary to calculate the number of lags of the endogenous variables of the model since an autoregressive coefficient is used in modeling of each variable. The determination of the number of lags depended on the likelihood test statistic [76].

This test is given by the following formula:

$$LR = -2(l_0 - l_1) \tag{8}$$

where l_i is the likelihood given by the VAR test with the use of $p_{0,1}$ lags. According to the results taken the number of lags chosen was equal to 3.

The LR trace statistic and the maximum eigenvalue LR test were employed for the determination of the number of the relations connecting the variables under preview (rank of r). In particular this statistic test the null hypothesis of r cointegrating relations against k cointegrating relations (r = 0, 1, 2, . . ., k − 1).

The LR trace statistic is calculated with the formula:

$$LR\left(\frac{r}{k}\right) = -T\sum_{i=r+1}^{k}\ln(1-l_i) \tag{9}$$

The critical values employed are based on Osterwald–Lenum, which differ slightly from those reported in Johansen and Juselius [77,78].

Another statistic employed within the framework of the Johansen cointegration technique is the trace statistic. This is based on the following function:

$$F = \{F_1(t), \ldots, F_{n-r}(t)\} \tag{10}$$

This function is defined as follows:

$$F_j(t) = W_j(t) - \int_0^1 W_j(s)\,ds \tag{11}$$

The statistic function given by Eq. (11) consist the trace statistic.

In the second stage the dynamic error correction model of Granger–Engle Granger process was applied [79]. The particular models have the following form and are given by the following Eqs. (10a), (10b) and (10c):

$$\Delta PP_1 = \mu_1 + \sum_{t=1}^{n_1}\beta_{pp1}\,\Delta PP_{1t-1} + \sum_{t=0}^{n_2}\beta_{pp2}\,\Delta PP_{2t-1} + \sum_{t=3}^{n_3}\beta_{pp3}\,\Delta PP_{3t-1} - \pi_1 Z_{t1-1} + e_{t1} \tag{10a}$$

$$\Delta PP_2 = \mu_1 + \sum_{t=1}^{n_1}\beta_{pp1}\,\Delta PP_{1t-1} + \sum_{t=0}^{n_2}\beta_{pp2}\,\Delta PP_{2t-1} + \sum_{t=3}^{n_3}\beta_{pp3}\,\Delta PP_{3t-1} - \pi_2 Z_{t2-1} + e_{t2} \tag{10b}$$

$$\Delta PP_3 = \mu_1 + \sum_{t=1}^{n_1}\beta_{pp1}\,\Delta PP_{1t-1} + \sum_{t=0}^{n_2}\beta_{pp2}\,\Delta PP_{2t-1} + \sum_{t=3}^{n_3}\beta_{pp3}\,\Delta PP_{3t-1} - \pi_3 Z_{t3-1} + e_{t3} \tag{10c}$$

The possible results of this method are the following:

(a) $\pi_1 \neq 0,\ \pi_2 \neq 0,\ \pi \neq 0$ There is a long-term two-way relationship between the three variables.
(b) $\pi_1 = 0,\ \pi_2 \neq 0\ \pi_3 \neq 0$ In the long run the producer price of the beech fuelwood is not Granger caused by the producer price of the other two fuelwood species, while the opposite is valid for the two other fuelwood species.
(c) $\pi_1 \neq 0,\ \pi_2 = 0\ \pi_3 \neq 0$ In the long run the oak producer price is not Granger caused by the producer price of the other two.
(d) $\pi_1 \neq 0,\ \pi_2 \neq 0\ \pi_3 = 0$ In the long run only the conifers fuelwood producer price is not Granger caused by the other two variables.
(e) $\pi_1 = 0,\ \pi_2 = 0,\ \pi_3 \neq 0$ In the long only the coniferous fuelwood producer price is Granger caused by the other two variables.
(f) $\pi_1 \neq 0,\ \pi_2 = 0\ \pi_3 = 0$ In the long only the beech fuelwood producer price is Granger caused by the other two variables.
(g) $\pi_1 = 0,\ \pi_2 \neq 0\ \pi_3 = 0$ In the long only the oak fuelwood producer price is Granger caused by the other two variables.

The next part of the methodology employed involved an impulse-response analysis of the three variables studied. The generalized impulse responses provides a tool for describing the dynamics in a time series model by mapping out the reaction in, the fuelwood price of conifers for instance to a one standard deviation shock to the residual in the fuelwood price of the two other species [80].

The VAR process we consider is the following:

$$x_t = \Phi D_t + \sum_{i=1}^{k}\Pi_i x_{t-i} + \varepsilon_t \quad t = 1, 2, \ldots, T \tag{11'}$$

The process x_t representing the vector of prices is covariance stationary, integrated of order d (and possibly cointegrated), while ε_t is p dimensional and assumed to be i.i.d. (identically, independently, distributed) with zero mean and positive definite covariance matrix Ω.

The h-ahead forecast error for the x_t process is given by the following equation:

$$x_{t+h} - E[x_{t+h}/I] = \sum_{j=0}^{h-1} C_j\varepsilon_{t+h-j} \tag{12}$$

where I is an information set which includes the history of x_s up to and including period t as well as the entire time path for D_t. The $p \times p$ matrices C_j are given by $C_0 = Ip$ and

$$C_j = \sum_{i=1}^{\min k,j}\Pi_i C_{j-i} \quad j \geq 1 \tag{13}$$

so that all C_j matrices can be determined recursively from the Π_i matrices.

The generalized impulse response function defined by the following equation [81]:

$$GI_x(h, \delta, I_{t-1}) = E[x_{t+h}/\varepsilon_t = \delta,\ I_{t-1}] - E[x_{t+h}/I_{t-1}] \tag{14}$$

where δ is some known vector. For the VAR process this means that:

$$GI_x(h, \delta, I_{t-1}) = G_h\delta \tag{15}$$

The choice of δ is therefore central to determining the time profile for any generalized impulse response function. As an alternative to shocking all elements of ε_t one may consider just shocking one element such that $\varepsilon_{jt} = \delta_j$. We may now define the generalized impulse responses as:

$$GI_x(h, \delta_j, I_{t-1}) = E[x_{t+h}/\varepsilon_{jt} = \delta_j,\ I_{t-1}] - E[x_{t+h}/I_{t-1}] \tag{16}$$

Letting $\delta_j = (\omega_{jj})^{1/2}$, the standard deviation of ε_{jt}, and assuming that ε_t is Gaussian, it follows that:

$$E[\varepsilon_t/\varepsilon_{jt} = \sqrt{\omega_{jj}}] = \Omega e_j\omega_{jj}^{-1/2} \tag{17}$$

Table 1
Results of unit root tests.

Variables	KPSS test	PP test	ADF test
p_{conifers}	0.779731	0.536179	−2.259494
$\Delta p_{\text{conifers}}$	0.188692	−5.875684	−6.030170
p_{oak}	0.791974	0.879496	−1.9927
Δp_{oak}	0.338052	−5.608791	−5.564810
p_{beech}	0.795847	1.079047	−2.038426
Δp_{beech}	0.289409	−6.236366	−5.557170

Notes: The critical values for the ADF test and for 1, 5 and 10% significance values are −4.198503, −3.523623, −3.192902 of the KPSS test −3.600987, −2.935001, −2.605836 and the KPSS test 0.739000, 0.463000, 0.347000 regarding the ADF critical values for the first differences are −4.192337, −3.520787, −3.191277 for 1, 5, 10% levels of significance respectively.

where e_j is the jth column of Ip. For the VAR model we then find that:

$$GI_x(h,\ \sqrt{\omega_{jj}}, I_{t-1}) = C_h \Omega e_j \omega_{jj}^{-(1/2)} \tag{18}$$

This measures the response in x_{t+h} from a one standard deviation shock to ε_{jt}, where the correlation between ε_{jt} and ε_{it} is taken into account. Defining the diagonal $p \times p$ matrix Σ as:

$$\Sigma = \begin{bmatrix} (e_1' \Omega e_1)^{-1/2} \\ (e_2' \Omega e_2)^{-1/2} \\ (e_2' \Omega e_2)^{-1/2} \\ \ldots \\ (e_p' \Omega e_p)^{-1/2} \end{bmatrix} \tag{19}$$

we may express the generalized impulse responses in matrix form as:

$$GI_x(h, \sqrt{\omega_{11}}, \ldots, \sqrt{\omega_{pp}}, I_{t-1}) = C_h \Omega \Sigma = C_h B = A_h \tag{20}$$

where column j is given by $GI_x(h,\ \sqrt{\omega_{jj}}, I_t), I_{t-1}$. When Ω is diagonal, then $B^* \Omega^{1/2*} \Sigma^{-1}$, is a diagonal matrix with standard deviations along the diagonal.

Finally, we conducted a forecast errors variance decomposition analysis. This analysis provides a decomposition of the variance of the forecast errors of the variables in the VAR at different time horizons [82]. The procedure used in the present study is the generalized forecast error variance decomposition. The particular method considers the proportion of the variance of the N-step forecast errors of z_t hat explained by conditioning on the non-orthogonalized shocks allowing though for correlations to these shocks, which in turn affect the other equations of the system under preview. The generalized forecast error variance decomposition is provided by the following formula:

$$y_{ij,N} = \frac{\sum_{l=0}^{N} (GI_{i,j,l})^2}{\sum_{l=0}^{N} e_j' A_l \sum A_l' e_j} \tag{21}$$

The forecast error variance is a result of future shocks to the i-equation.

$\sum (GI_{i,l,j})^2$ represents the sum of the squares of the generalized responses of the shocks to the i equation and the j variable. e_j represents the shocks.

A_l represents the coefficient matrices in the MA representation.

$\sum_{l=0}^{N} A_l A \Sigma A_l'$ represents the total forecast error covariance matrix.

4. Results

As mentioned above, we initially implemented different unit root and stationarity tests (ADF, KPSS, Phillips Perron tests). The results of those tests are presented in Table 1.

Table 2
Results of trace statistic.

Trace statistic	95% Critical value
70.73719	42.91525
23.39801	25.87211
8.726117	12.51798

Table 3
Results of the maximum eigenvalue statistic.

Null hypothesis	Maximum eigenvalue statistic	95% Critical value
$r=0$	47.33918	25.82321
$r \le 1$	14.67189	19.38704
$r \le 2$	8.726117	12.51798

According to the results given in Table 1 all the variables given above are $I(1)$, as confirmed with all the unit root tests applied. This implies that we cannot reject the null hypothesis in levels for all the variables used, while in first differences the variables are stationary. Consequently, we can examine whether a there is a combination of those prices that is stationary.

This objective may be achieved with the application of the Johansen cointegration technique. The results of the trace statistic are given in Table 2.

According to the results of the trace statistic test presented above we reject the null hypothesis in the first two cases implying that there is a sole relationship between the producer prices of the three different fuelwood forest species.

The results of the maximum eigenvalue statistic are presented in Table 3.

On the contrary, the maximum eigenvalue statistic indicated no cointegration between the three prices under preview. This result implies that the prices of the three different fuelwood forest species are not interrelated and consequently different market conditions determine their formation.

The next step in our study involves the implementation of weak exogeneity test. This test includes first of all the estimation of the Vector Error Correction Model (VECM) (Tables 4 and 5).

According to the results presented above the coefficient of the cointegrating equation is significant at 5% significance level only when the producer price of oak is the dependent variable. Regarding the residuals of the VECM we can argue that the residuals of

Table 4
Results of estimation of VECM.

Error correction	$D(p_{\text{oak}})$	$D(p_{\text{beech}})$	$D(p_{\text{conifers}})$
CointEq1	−1.239553	−0.406420	−0.530265
	(0.35862)	(0.33207)	(0.27481)
	[−3.45644]	[−1.22390]	[−1.92956]
$D(p_{\text{oak}}(-1))$	0.228438	0.184771	0.298653
	(0.36521)	(0.33817)	(0.27986)
	[0.62549]	[0.54638]	[1.06714]
$D(p_{\text{oak}}(-2))$	−0.409228	−0.247676	0.133359
	(0.31528)	(0.29194)	(0.24160)
	[−1.29797]	[−0.84838]	[0.55198]
$D(p_{\text{beech}}(-1))$	−1.378934	−0.654056	−0.495360
	(0.60175)	(0.55720)	(0.46112)
	[−2.29155]	[−1.17383]	[−1.07425]
$D(p_{\text{beech}}(-2))$	−0.333242	−0.057161	−0.261815
	(0.51951)	(0.48104)	(0.39810)
	[−0.64146]	[−0.11883]	[−0.65767]
$D(p_{\text{conifers}}(-1))$	1.343798	0.616807	0.173924
	(0.31301)	(0.28984)	(0.23986)
	[4.29311]	[2.12811]	[0.72510]
$D(p_{\text{conifers}}(-2))$	1.140404	0.602853	−0.028339
	(0.34771)	(0.32197)	(0.26645)
	[3.27975]	[1.87240]	[−0.10636]
R-squared	0.606191	0.218444	0.066893
Adj. R-squared	0.534590	0.076343	−0.102763

Table 5
The residuals of the VECM.

Test	Q_{stat}	LM_2	LM_4	Lutkepohl–Jarque–Bera	White heteroskedasticity
Statistics	13.0588	13.39949	19.20457	10.00402	144.5805
P	0.1322	0.1453	0.0235	0.1245	0.0108

the model suffer only from heteroskedasticity for 10% significance level and autocorrelation of fourth order. Furthermore the fact that the cointegrating equation is significant only in the first equation implies that the oak producer price is affected by the producer prices of the other two forest species. Thus the cointegrating vector that interrelate the three producer prices is the one where the oak producer price is normalized. In particular, the cointegrating vector is given by the following equation:

$$\Delta p = \underset{(0.35388)}{0.712484}\,\Delta p_{\text{beech}} - \underset{(0.38656)}{1.737975}\,\Delta p_{\text{conifers}} + \underset{(0.00794)}{0.03t}$$

According to the signs of the cointegrating vector we may conclude that an increase in the price of the beech implies an increase in the producer price of the oak while an increase in the producer price of the conifers implies a decrease in the oak producer price of greater size.

This result may be interpreted as follows; oak and beech behave as complimentary fuelwood species while conifers and oak fuelwood behave as substitutes. As mentioned above beech fuelwood does have the greater heating value. Consequently, the producer price of the beech fuelwood plays an important role in the producer price of the oak fuelwood. In addition time trend and coniferous fuelwood producer price is statistically significant in the formation of the oak producer fuelwood price. The next step in our analysis involves the impulse-response analysis [80,83]. In particular, an innovation leading to a change in the oak producer price of a standard deviation causes also a change in the prices of the other two producer prices. To be more specific in the second time period a reduction in the oak producer price is observed, while a reduction in the beech producer price of a smaller size and an important increase in the conifers producer price.

This result becomes apparent in Table 6.

As it becomes evident the response of producer oak fuelwood price on one S.D. innovation is significant for the case of beech producer fuelwood price impulse mainly after the third period. In particular a significant increase of oak producer price can be observed while the opposite is valid for the case of the conifers producer fuelwood price. Regarding the beech fuelwood producer price a slight decrease is observed in the second period and after one S.D. change in the coniferous fuelwood producer price. Significant decrease though is evident as response of the beech fuelwood producer price in one S.D. innovation of oak fuelwood producer price. Finally, a one S.D. innovation in oak fuelwood producer price leads to negative change of the conifers producer fuelwood prices while change in the beech fuelwood producer price is the impulse for significant response of the coniferous fuelwood producer price after the third period.

The final step in our analysis involves a variance decomposition analysis the results of which are given in Fig. 2.

As we can conclude from the variance decomposition analysis the volatility of the coniferous fuelwood producer price can be interpreted mainly by the volatility of the beech fuelwood producer price almost 60%, while the oak volatility is interpreted by the volatility of the beech fuelwood producer price, as well as by the volatility of the coniferous fuelwood producer price in great proportion. Finally, regarding the volatility of the beech fuelwood, the change of the fuelwood prices of the other two forest species studied becomes evident, especially after the fifth period and reaches about 20% of its total volatility. This result does also confirm the existence of a relationship between the prices of the three fuelwood forest species.

The results presented above have important implications for the implementation of the energy policy. Forests ecosystems can serve as carbon stocks and consequently the species choice is an important management decision [46]. The interrelation between the prices of the different species provides the policy makers with the ability to encourage or prevent the consumption of fuelwood of the three different species in order the objectives of carbon storage, to be achieved. Thus, the price signals can contribute to the conservation of the oak forests necessitated by its ability to function more effectively as a carbon storage forest ecosystem compared to those of the other two forest species.

5. Conclusions

The substitution of the fossil fuels with bioenergy can contribute substantially to the reduction of the greenhouse effect. Thus, the extensive use of this type of energy provides the policy makers with an efficient environmental tool not only in the long but also in the short term.

Energy production based on biomass has important social and financial impacts on agricultural and mountainous regions. All these consequences are related to the following sectors; employment and regional development, the diversity in the use of energy resources and land use, institutional and policy issues (subsidies, investments financing, the selling process of electricity produced by

Table 6
Impulse-response analysis (generalized on S.D. innovation).

Period	p_{oak}	p_{beech}	$p_{conifers}$
Response of p_{oak}			
1	2.758091	0.000000	0.000000
2	−0.030657	1.921605	1.170611
3	−2.572189	5.245860	1.104752
4	−1.562732	6.543211	−1.279235
5	−1.912565	6.526807	−0.577048
6	−2.991772	7.083232	0.727195
7	−2.252904	7.049990	−0.160022
8	−2.107772	6.852109	−0.366202
9	−2.783736	7.199360	0.231577
10	−2.547803	7.301622	−0.085634
Response of p_{beech}			
1	0.000000	2.553889	0.000000
2	−0.611328	2.668214	0.756237
3	−2.053197	4.266652	1.133346
4	−1.677352	4.957527	−0.023187
5	−1.756969	5.080802	0.002671
6	−2.334390	5.382812	0.667623
7	−2.073753	5.423992	0.367730
8	−1.916251	5.297191	0.200657
9	−2.229132	5.432154	0.482617
10	−2.178492	5.514613	0.379400
Response of $p_{conifers}$			
1	0.000000	0.000000	2.113528
2	−0.638808	1.063460	1.766911
3	−1.237402	2.151500	1.093426
4	−1.670000	3.119384	0.815800
5	−1.710771	3.323302	0.921514
6	−1.744096	3.306059	1.126565
7	−1.763441	3.314082	1.148649
8	−1.767286	3.367925	1.062086
9	−1.804078	3.423835	1.046022
10	−1.825833	3.453995	1.064547

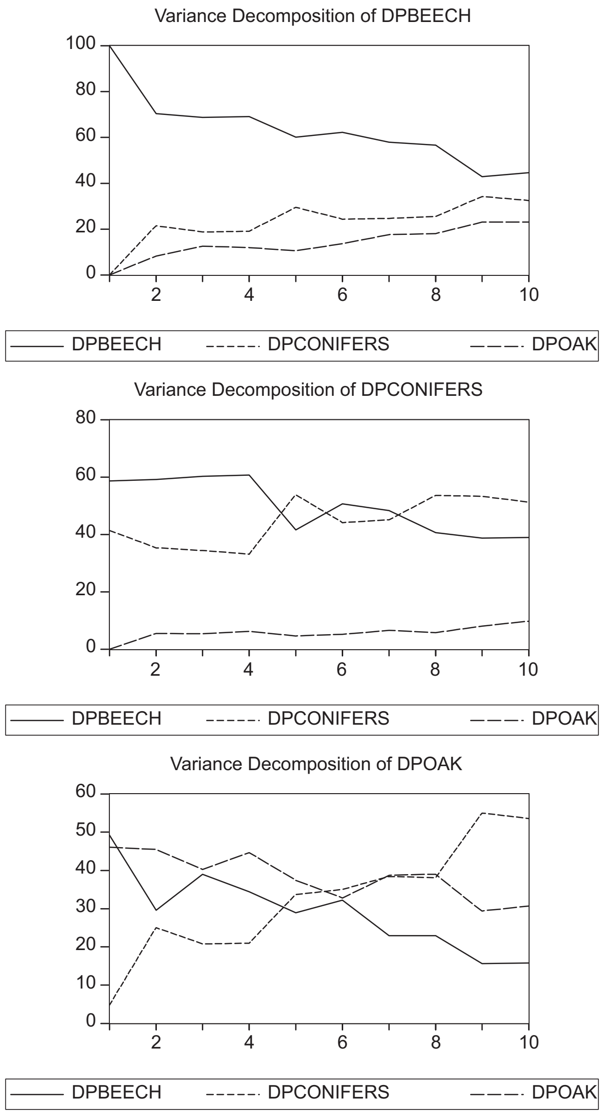

Fig. 2. Variance decomposition analysis.

biomass, the taxation, the public revenues and the environmental regulations).

The present paper surveys the behaviour of the producer prices of three different fuelwood forest species. Demand analysis in the products of the primary sector (like fuelwood) with the assistance of mathematic models may well be misleading, given that the quantities are the endogenous variables in the model, while the prices are the exogenously determined variables. This fact implies that the equilibrium in the market is a result of prices adjustment to the quantities and not vice versa. A significant particularity of the market studied is that the data employed involve prices formatted in auctions that take place between the wholesalers and the state forest farms. The prices formatted in public auctions may well be leaders for the negotiation prices for the wood supply (and the supply of the fuelwood as well) that come from non-state forestry. In addition, it is of great importance for the formation of fuelwood prices the fact that the main wood product of oak forests is the fuelwood contrary to the coniferous and the beech forest, the main wood product of which is technical–industrial wood of great size. This may account for the interpretation of some of the results found.

For the achievement of the objectives of the study a series of econometric tests was applied. Initially, the stationarity of the three variables was studied with the application of unit root test (ADF test). ADF test confirmed that all of the time series studied are integrated of order 1,($I(1)$). This result implies that their combination could be $I(0)$, and consequently all the time series are cointegrated (the prices are characterized by co-movements and thus common factors may account for their formation). According to the results of the Johansen cointegration technique and based on the trace as well as on maximum eigenvalue statistic only one cointegrating vector interrelates the three producer prices, while the VECM indicated that the oak producer price is Granger caused by the producer prices of the other two forest species. According to the signs of the cointegrating vector, we conclude that an increase in the conifers price leads to a significant decrease in the oak price, while an increase in the beech price leads to a slight decrease in the oak price. The coefficients of the prices in the cointegration vector express elasticities given that each variable is expressed in logarithmic form. In addition within the particular survey, an impulse response and variance decomposition analysis was also conducted and the results confirmed those of the cointegration analysis. Consequently, the fuelwood prices of the three forest species are interrelated and internal mechanisms may account for the formation of the producer fuelwood prices.

The interrelation of the prices may well serve for the implementation of an energy policy. In particular, the employee of the price signals along with the sustainable management of the existent oak forests can lead to an improvement of the Greek forests as carbon dioxide storage.

In addition, the oak forests as well as the energy plantations or cultivations, developed in agricultural areas may contribute to the solutions of energy problems. The increasing participation in the energy balance of Greece and the trend for a limitation of dependence from oil imposes the country to a rational exploitation of the natural resources.

In particular, the oak forests exploitation (as forests producing mainly fuelwood) that till today have been unexploited as well as the direction to exploitation of agricultural lands with plantations of short time rotation (i.e. poplars), may become new sources for rational exploitation. The process will be determined by the worldwide price evolution of liquid fossil fuels (oil, gas, etc.), the geopolitical drift in their production countries, the gradual decrease of their stocks and the need for the decrease of air pollution caused by oil fuels burning. In addition, the conservation and the exploitation of oak forests with silvicultural treatments and other management measures due to the stability of those ecosystems may well contribute the long term in the storage of greater carbon quantities compared to the coniferous forests.

To conclude, for the achievement of the quantity and quality improvement of the fuelwood in Greece the following forest policy measures are necessary:

- The completion and improvement of the forest road network.
- The modernization of the woodcutting and harvesting methods especially of the oak forests given that they mainly produce fuelwood and in addition the cost harvest and transportation may overcome even and their sale price.
- Increase in the forest investments.
- Improvement in the conditions of the fuelwood distribution and turnover as well as of the other forest products.

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